Technical Note N-1007

CORROSION OF DSRV MATERIALS IN SEA WATER - 3 MONTHS EXPOSURE

By

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ABSTRACT

A sea water exposure program was initiated to determine: (1) the effects of galvanic and crevice corrosion on selected combinations of alloys; and (2) the efficacy of sealing compounds, paint coatings and galvanic anodes for preventing corrosion, crevice corrosion and galvanic corrosion. Evaluations of the results of 91 days of exposure at mean tide level in sea water showed that:

1. A polyurethane paint system
   (a) effectively protected
      (1) anodized 6061-T6 aluminum alloy
      (2) glass reinforced plastic
      (3) 6Al-4V titanium alloy
      (4) 13V-11Cr-3Al titanium alloy
   (b) prevented galvanic corrosion between dissimilar metal combinations
   (c) prevented crevice corrosion.
2. The sealing compounds for excluding sea water from crevices in order of effectiveness from best to worse were:
   (a) PR1532
   (b) DC780
   (c) DC93046
   (d) PR1422
   (e) PR1527
   (f) DC11
   (g) sprayed PVC.
3. No corrosion occurred on:
   (a) Unprotected anodized 6061-T6 aluminum alloy fasteners,
   (b) 5052 aluminum alloy rivets,
   (c) A-286 corrosion resistant steel fasteners,
   (d) 6Al-4V titanium alloy fasteners.

4. Cadmium plated steel washers

(a) corroded galvanically when in contact with titanium and A-286 corrosion steel fasteners

(b) by ordinary corrosion when isolated from 6061-T6 aluminum alloy fasteners by an anodic coating.

5. Delrin plastic strips, sleeves and washers were effective in isolating metal parts from each other; hence, preventing galvanic corrosion.

6. A zinc anode prevented corrosion and galvanic corrosion on an anodized aluminum alloy 6061-T6 panel with anodized 6061-T6 strips attached to it with Type 304 stainless steel and nickel-copper 400 alloy rivets.

7. A zinc anode did not prevent corrosion at the faying surfaces between a 6061-T6 aluminum alloy panel and 13V-11Cr-3Al titanium alloy strips but it did prevent corrosion and galvanic corrosion on the exposed surfaces.

PREFACE

Soon after the Lockheed Missile and Space Company, Sunnyvale, California, was awarded the contract, (NObs 63A), to construct the first Deep Submergence Rescue Vessel (DSRV) for the U. S. Navy under the cognizance of the Deep Submergence Systems Project, it became apparent that information about many corrosion problems was required.

During consultations with NCEL personnel regarding these corrosion problems, it became evident that reliable information about some of these problems was not available in the literature. The lack of this information prompted the initiation of a sea water corrosion test program to obtain such information.

Therefore, a corrosion test program was initiated in December 1967. Specimens were exposed at mean tide level at the Point Mugu exposure site. At mean tide level the specimens are exposed to the air at low tides and are completely immersed in the sea water at high tides.

This report contains the results after three months of exposure.

INTRODUCTION

The design of the Deep Submergence Rescue Vessels specified the use of many dissimilar alloys some of which would be in intimate contact with each other. Two dissimilar metals in intimate (electrical) contact with each other can result in two types of dangerous corrosion, galvanic and crevice, especially when immersed in sea water. Galvanic corrosion can be very rapid when the area of the cathodic (more noble) alloy is much larger than that of the anodic (less noble) alloy.

Because of the multitude of possible dissimilar metal combinations, sometimes as many as three or four different alloys in contact with each other, or because the configuration is such that there would be an electrical path connecting all of them, a sea water test program was initiated to determine:

1. The effects of galvanic corrosion on selected combinations of alloys.

2. The efficacy of sealing compounds in preventing crevice corrosion.

3. The value of paint coatings for preventing galvanic corrosion.

4. The value of galvanic anodes in preventing corrosion, galvanic corrosion of dissimilar metal combinations, and corrosion in crevices.

Specimens simulating the four conditions above were exposed at mean tide level at the Point Mugu site for evaluation.

The geographical location of the Point Mugu site and the characteristics of the sea water are:

Latitude, North	34°06'
Longitude, West	119°07'
Temperature, °C	12-19
Oxygen, ml/l	3.9-6.6
Salinity, °/oo	33.51
pH	8.1
Current, Knots	Variable

This report is a discussion of the results obtained after 91 days of exposure.

RESULTS AND DISCUSSION

The specimens, their component parts, the protective systems, the sealing compounds for filling crevices and coating fasteners, and the results of visual examinations after exposure are given in Table 1.

Specimen G1B

The paint had flaked on the panel at two areas; there were many small barnacles attached especially on sealant PR1523 although the alloy underneath had not corroded at the areas of paint failure.

The paint failed on four of the six strips, chiefly along the edges or at the corners. On one strip the paint had flaked at one area on the surface. There was no paint failure on the faying surfaces of either the panel or the strips.

There was no failure of the sealants at the faying surfaces but sealants DC11 and DC93046 were gone from the heads of the fasteners. DC11 and PVC spray sealants were much inferior to the other three sealing compounds: DC780, Pk1532 and DC93046.

The bolts and nuts on all the strips were uncorroded; however, the cadmium plated washers underneath the nuts on strip No. 1 which was not sealed were corroded on the edges. Measurements with a volt-ohm meter showed that there was an electrical conducting path of very low resistance between the bolts but there was a very high resistance (no electrical conducting path) between the fasteners and the cadmium plated steel washers. When steel and an aluminum alloy are in contact with each other by an electrical conducting path in sea water, the aluminum alloy will corrode at a faster rate than its normal rate thus preventing the steel from corroding. Since there was no electrical contact between the cadmium plated steel washers and the 6061-T6 fasteners because of the anodized coating on the fasteners, the steel washers corroded at their normal rate in sea water after the cadmium plating had been removed by corrosion.

Specimen G2B

The painted panel had failed by flaking at the corners, one area being about 3/4 square inch in size.

There were no paint failures on the strips. When the strips were removed from the panels, the outer top coat of paint was stripped from the panel indicating poor adhesion between the two top coats of paint.

The sealing compounds effectively sealed the crevices between the faying surfaces of the panel and the strips.

The rivets were uncorroded.

Specimen G3B

The paint on the panel had not failed. The paint coating was stained with rust below the nuts and washers from strip No. 5.

There were paint failures along the edges and on the surfaces of some of the strips. The paint had flaked from as much as 20 percent of the top surface of strip No. 3. The anodized and painted 6061-T6 strips were corroded (white corrosion products) where the paint had failed along the edges.

The sealants had become detached from the heads of the fasteners. The adhesion of sealants DC780, PR1532 and DC93046 to the faying surfaces of the strips and the panel was excellent.

There were no paint failures at the faying surfaces of the strips and the panel; however, there were rust stains on the faying surfaces of strip No. 5 and on the panel.

The fasteners on all strips except No. 5 were uncorroded. However, there were white corrosion products on the outside surfaces of the sleeves which resulted from the corrosion of the aluminum alloy strips and panel in the bolt holes. There were cadmium plated steel washers and silver plated steel nuts on the bolts of strip No. 5 in place of the clinching type of nuts made for this type of bolt and sleeve assembly. The cadmium plated steel washers were anodic to both the A-286 sleeve and bolt and the silver plated nut thus resulting in rapid galvanic corrosion of the washers.

Specimen G4B

The paint had failed at the corners of the panel and the corners were rounded due to corrosion. The rounding of the corners of the panels was due to galvanic corrosion because of the electrical contact between the anodic panel and the cathodic bolts and nuts. There were rust stains on the panel at strips No. 1, 2, 3, 5 and 6. Barnacles were attached to the strips, chiefly on the exposed sealants.

There were no paint failures on the strips or at the faying surfaces of the strips and the panel.

There was failure of the sealants on the nuts of the fasteners. The adhesion of sealants DC780, PR1422 and DC93046 to the strips and panel was very good.

The cadmium plated steel washers used with the 6Al-4V titanium bolts and nuts were severely corroded galvanically because of the electrical contact between the anodic washers and the cathodic nuts and bolts except at strip No. 4.

Specimen G5B

There were paint failures at the corners of the panel and the corners were rounded by corrosion. The rounding of these corners was due to galvanic corrosion because of the electrical contact between the anodic aluminum alloy panel and the cathodic A-286 stainless steel bolts and nuts. There were rust stains on the panel at the nuts and washers on strips No. 1, 2, 3, 5 and 6.

There were no paint failures on the strips or their faying surfaces with the panel.

Sealant DC93046 had failed on the heads of the fasteners. The adhesion of sealants DC780, PR1532 and DC93046 was excellent at the faying surfaces of the strips and panels.

The cadmium plated steel washers used with the A-286 stainless steel bolts and nuts were corroded galvanically because of the electrical contact between the anodic washers and the cathodic fasteners except at strip No. 4.

Specimen G6B

There were no paint failures on the panel, on the strips or at the faying surfaces of the strips and the panel.

The silver plated steel nuts on the 6Al-4V titanium bolts on strip No. 6 had rusted at pinholes in the silver plate.

Specimen G8B

The anodic coating on the panel and the surfaces of the strips exposed to the sea water had disappeared. However, there were no indications of corrosion on either the panel or the strips.

The anodic coating was intact on the faying surfaces of the strips and the panel.

Neither the Type 304 stainless steel nor the nickel-copper 400 alloy rivets were corroded.

The zinc anode attached to the panel was covered with a very thin layer of white corrosion products indicating very little consumption.

The absence of corrosion on the panel and on the strips indicated the protection afforded by both the anodic coating and the zinc anode. Usually, the anodic coating on aluminum alloys fails locally resulting in pitting. However, in this case the anodic coating seemed to fail uniformly and there was no pitting of the aluminum alloy panel and strips indicating that the zinc anode had prevented pitting.

Specimen G8F

The panel had turned a drab grey with no other indications of corrosion. The strips were uncorroded.

Neither the Type 304 stainless steel nor the Ni-Cu 400 alloy rivets were corroded. There were thin white corrosion products on the rivet countersink surfaces of the panel.

There were films of white corrosion products on the faying surfaces of the panel and the strips and the surface of the panel was etched.

The zinc anode was covered with a layer of white corrosion products and there was a few small pits on the surfaces of the anode indicating that it was being consumed.

The zinc anode protected the 6061-T6 aluminum alloy panel from corroding. Without the zinc anode the panel would have been pitted within three months in sea water; with the titanium alloy strips attached, the pitting would have been more intense because of the galvanic corrosion.

However, the white corrosion products at the rivet countersinks and on the faying surfaces of the panel indicate that there was corrosion of the 6061-T6 aluminum alloy at these surfaces and, also, that the zinc anode had not protected these crevice surfaces from corrosion.

Specimen G9B

There were three small areas of paint failure at the top edge of the panel.

There was no failure of sealant or of the paint at the faying surfaces.

The sealant on the head of one bolt had become detached.

There was no corrosion of the fasteners except for light rust stains on the head of the bolt from which the sealant had become detached.

The delrin sleeves, strips and washers effectively prevented electrical contact between the strips, panel and fasteners thus eliminating the possibility of galvanic corrosion.

SUMMARY

Specimens composed of different combinations of alloys, fasteners, surface coatings, paint systems, sealing compounds and galvanic anodes were exposed at mean tide level in the Pacific Ocean to evaluate the efficacy of the protective systems for alleviating galvanic and crevice corrosion. The composite specimens simulated fabricating practices encountered in the construction of the first Deep Submergence Rescue Vessel (DSRV) for the Navy.

This report presents the results of the evaluation of a set of specimens removed after 91 days of exposure.

The paint system provided very good protection to the:

(1) Anodized 6061-T6 aluminum alloy panels;
(2) Glass reinforced plastic panels;
(3) Anodized 6061-T6 aluminum alloy strips;
(4) 6Al-4V titanium alloy strips;
(5) 13V-11Cr-3Al titanium alloy strips.

Most of the paint failures were along the edges of the panels and strips, and they are attributed to erosion by floating kelp and debris in the sea water.

The paint coating effectively prevented galvanic corrosion between the panels and the dissimilar metal strips.

The order of merit of the sealing compounds for excluding sea water from crevices and for protecting the heads and nuts of fasteners was, from best to worst:

1. PR1532
2. DC780
3. DC93046
4. PR1422
5. PR1527
6. DC11
7. Sprayed PVC.

There was no corrosion on:

1. Unprotected anodized 6061-T6 aluminum alloy fasteners,
2. 5052 aluminum alloy rivets
3. A-286 corrosion resistant steel fasteners
4. The 6Al-4V titanium alloy fasteners.

The cadmium plated steel washers were corroded in all cases where they had been used. There was no electrical connection between the cadmium plated steel washers and the anodized 6061-T6 aluminum alloy bolts and nuts; hence, there was normal corrosion of the washers. Had there been an electrical connection between the washers and the bolts, the anodic 6061-T6 bolts would have been expected to corrode to prevent corrosion of the steel washers after the cadmium plate had been sacrificed to protect both the steel washers and the 6061-T6 bolts.

In the other cases where the cadmium plated steel washers were used with A-286 corrosion resistant steel fasteners and 6Al-4V titanium alloy fasteners, there was an electrical path between them and the washers, being the anodes, were corroded galvanically.

One bolt assembly which consisted of A-286 flat head bolts, sleeves and nuts which crimped onto the bottoms of the sleeves had white corrosion products on the outer surfaces of the sleeves indicating that the aluminum alloy through which they penetrated had corroded.

The delrin plastic sleeves, strips and washers used to isolate 18Cr-8Ni bolts and nuts from an anodized 6061-T6 aluminum alloy panel and 13V-11Cr-3Al titanium strips effectively prevented any galvanic corrosion. However, some silver plated steel nuts used on some 18Cr-8Ni steel bolts were rust stained where the silver plating had failed.

A zinc anode attached to a bare 6061-T6 aluminum alloy panel to which was attached strips of 13V-11Cr-3Al titanium alloy with Type 304 stainless steel rivets and nickel-copper 400 alloy rivets effectively protected the composite specimen from corrosion and galvanic corrosion except at the faying surfaces. The faying surfaces of the titanium strips were coated with thin films of white corrosion products and the faying surfaces of the aluminum panel were etched, thus, indicating that the protective current of the zinc anode was ineffective.

A zinc anode attached to an anodized 6061-T6 aluminum alloy panel to which was attached anodized 6061-T6 aluminum alloy strips with Type

304 stainless steel rivets and nickel-copper 400 alloy rivets effectively protected this composite specimen from corrosion and galvanic corrosion.

Table 1. Specimens After Three Months of Exposure in Tidewater

Specimen	Remarks
Panel G1B	6061-T6 anodized[3] and painted;[2] electrical contact between fasteners and panel - none between fasteners and Cd plated steel washers
Front[1]	Paint flaked in two areas, base metal uncorroded
Back	No paint failure, many barnacles especially on PR1532 sealant
Strips	6061-T6 anodized[3] and painted;[2] HI-LOK 6061-T6 anodized fasteners, Cd plated steel washers
#1	No paint failure
Sealant-None	
Fasteners	No corrosion, edges of Cd plated washers corroded
Faying surfaces	No paint failure
#2	No paint failure
Sealant-DC780	No failure, good adhesion, many barnacles
Fasteners	No corrosion
Faying surfaces	No paint failure
#3	Paint failure along edges, many barnacles
Sealant-PR1532	No failure, excellent adhesion
Fasteners	No corrosion
Faying surfaces	No paint failure
#4	Paint failures along edges and on surface, many barnacles
Sealant-DC93046	Gone on one bolt head, very good adhesion at faying surfaces
Fasteners	No corrosion
Faying surfaces	No paint failure
#5	Paint failure along edges especially at two corners, few barnacles
Sealant-DC11	Gone from bolt heads, very little adhesion
Fasteners	No corrosion
Faying surfaces	No paint failure
#6	Paint failure along edges especially at two corners, few barnacles
Sealant-PVC spray	No failure, no adhesion
Fasteners	No corrosion
Faying surfaces	No paint failure

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimen	Remarks
Panel G2B	6061-T6 anodized[3] and painted[2]
Front[1]	Paint flaked 3/4 sq. in. top right corner, barnacles
Back	Paint flaked 1 sq. in. top left corner, barnacles
Strips	6061-T6 anodized[3] and painted;[2] 5052 rivets
#1	No paint failure, some barnacles
Sealant-None	
Fasteners	No corrosion, barnacles around rivet heads
Faying surfaces	No paint failure
#2	No paint failure, some barnacles
Sealant-PR1527	No failure, barnacles, good adhesion
Fasteners	No corrosion
Faying surfaces	Top coat of paint stripped from panel when strip removed
#3	No paint failure
Sealant-PR1422	No failure, good adhesion, barnacles
Fasteners	No corrosion
Faying surfaces	Top coat of paint stripped from panel when strip removed
#4	No paint failure
Sealant-DC93046	No failure, good adhesion, barnacles
Fasteners	No corrosion
Faying surfaces	Top coat of paint stripped from panel when strip removed
#5	No paint failure
Sealant-DC11	No failure
Fasteners	No corrosion
Faying surfaces	Top coat of paint stripped from one-half of panel underneath strip when it was removed
#6	No paint failure, barnacles
Sealant-PVC spray	No failure
Fasteners	No corrosion
Faying surfaces	Top coat of paint stripped from panel underneath strip when it was removed

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimen	Remarks
Panel G3B	6061-T6 anodized[3] and painted[2]
Front[1]	No paint failure, barnacles, especially at edges of strips
Back	No paint failure, barnacles, especially on sealant over nuts, rust stains from one nut on strip #5
Strips	6061-T6 anodized[3] and painted;[2] HI-LOK A-286 fasteners
#1	Paint failure on edges, few barnacles on sides
Sealant-None	
Fasteners	No corrosion
Faying surfaces	No paint failure
#2	Paint failure and slight corrosion on edges, slight white corrosion products in bolt holes
Sealant-DC780	Gone on heads of bolts
Fasteners	Slight white corrosion products on sleeves of fasteners, fasteners uncorroded
Faying surfaces	No paint failure
#3	Paint failure on edges, 20% gone on top of strip, some white corrosion products on strip and in one bolt hole
Sealant-PR1532	Gone on heads of bolts, excellent adhesion at faying surfaces
Fasteners	No corrosion, some white corrosion products on one sleeve
Faying surfaces	No paint failure
#4	Paint failure on edges, 10% flaked on top, white corrosion products in bolt holes
Sealant-DC93046	Gone on heads of bolts, excellent adhesion
Fasteners	No corrosion, slight white corrosion products on sleeves
Faying surfaces	No paint failure
#5	Paint failure and white corrosion products along edges
Sealant-DC11	Gone on bolt heads
Fasteners	Corrosion of Cd plated steel fasteners underneath nuts, electrical contact between fasteners and washers
Faying surfaces	No paint failure, rust stains on panel and strip
#6	Paint failure and white corrosion products along edges, white corrosion products in bolt holes
Sealant-PVC spray	Gone on bolt heads
Fasteners	No corrosion, white corrosion products on sleeves
Faying surfaces	No paint failure

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimen	Remarks
Panel G4B	6061-T6 anodized[3] and painted[2]
Front[1]	No paint failure except at corners paint gone and panel corners corroded same at insulators, barnacles at strips
Back	No paint failure, barnacles around sealants covering nuts, rust stains at fasteners from strips #1, #2, #3, #5, and #6
Strips	6Al-4V, painted,[2] HI-LOK 6Al-4V fasteners with Cd plated steel fasteners, electrical contact between fasteners and washers
#1	No paint failure
Sealant-None	
Fasteners	No corrosion except rust on Cd plated washers
Faying surfaces	No paint failure
#2	No paint failure
Sealant-DC780	No failure, good adhesion
Fasteners	No corrosion except rust on Cd plated washers
Faying surfaces	No paint failure
#3	No paint failure
Sealant-PR1422	No failure, excellent adhesion
Fasteners	No corrosion except rust on Cd plated washers
Faying surfaces	No paint failure
#4	No paint failure
Sealant-DC93046	No failure except on fasteners, good adhesion
Fasteners	No corrosion
Faying surfaces	No paint failure
#5	No paint failure
Sealant-DC11	No failure, good adhesion
Fasteners	No corrosion except rust on Cd plated washers
Faying surfaces	No paint failure
#6	No paint failure
Sealant-PVC spray	No failure
Fasteners	No corrosion except rust on Cd plated washers
Faying surfaces	No paint failure

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimen	Remarks
Panel G5B	6061-T6 anodized[3] and painted[2]
Front[1]	Paint failures and corrosion of 6061-T6 at 3 corners and bottom insulator, barnacles at strips
Back	No paint failure, some barnacles, rust stains at nuts and washers on strips #1, #2, #3, #5, and #6.
Strips	6Al-4V, painted,[2] HI-LOK A-286 fasteners, electrical contact between washers and fasteners
#1	No paint failure
Sealant-None	
Fasteners	No corrosion except rust on Cd plated steel washers
Faying surfaces	No paint failure
#2	No paint failure
Sealant-DC780	No failure, good adhesion
Fasteners	No corrosion except rust on Cd plated steel washer on one fastener
Faying surfaces	No paint failure
#3	No paint failure
Sealant-PR1532	No failure, excellent adhesion
Fasteners	No corrosion except rust on Cd plated steel washer on one fastener
Faying surfaces	No paint failure
#4	No paint failure
Sealant-DC93046	Gone on heads of fasteners, good adhesion
Fasteners	No corrosion
Faying surfaces	No paint failure
#5	No paint failure
Sealant-DC11	No failure
Fasteners	No corrosion except rust on Cd plated steel washers
Faying surfaces	No paint failure
#6	No paint failure
Sealant-PVC spray	No failure
Fasteners	No corrosion except rust on Cd plated steel washers
Faying surfaces	No paint failure

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimen	Remarks
Panel G6B	Glass reinforced plastic (GRP), painted[2]
Front[1]	No paint failure, few barnacles
Back	No paint failure, few barnacles
Strips	13V-11Cr-3Al, painted,[2] HI-LOK 6Al-4V bolts and silver plated A-286 nuts
#2	No paint failure
Fasteners	No corrosion
Faying surfaces	No paint failure
#6	No paint failure
Fasteners	Rust on silver plated steel nuts
Faying surfaces	No paint failure

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimens	Remarks
Panel G8B	6061-T6 anodized,[3] zinc anode attached
Front[1]	Anodic coating mostly gone, no corrosion, barnacles heavy on top half, Zn anode
Back	Anodic coating mostly gone, no corrosion
Strips	6061-T6, anodized,[3] Type 304 stainless steel and Ni-Cu 400 rivets
#1	Anodic coating gone, no corrosion, few barnacles
304 SS Rivets	No corrosion
Faying surfaces	No corrosion, anodic coating intact
#2	Anodic coating gone, no corrosion, few barnacles
304 SS Rivets	No corrosion
Faying surfaces	No corrosion, anodic coating intact
#3	Anodic coating gone, no corrosion, few barnacles
304 SS Rivets	No corrosion
Faying surfaces	No corrosion, anodic coating intact
#4	Anodic coating gone, no corrosion, few barnacles
Ni-Cr 400 Rivets	No corrosion
Faying surfaces	No corrosion, anodic coating intact
#5	Anodic coating gone, no corrosion, few barnacles
Ni-Cr 400 Rivets	No corrosion
Faying surfaces	No corrosion, anodic coating intact
#6	Anodic coating gone, no corrosion, few barnacles
Ni-Cr 400 Rivets	No corrosion
Faying surfaces	No corrosion, anodic coating intact

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimens	Remarks
Panel G8F	6061-T6, Zn anode attached
Front[1]	Dark grey, Zn anode covered with white corrosion products with few small pits
Back	Dark Grey
Strips	13V-11Cr-3Al, Type 304 stainless steel and Ni-Cu 400 alloy rivets
#1	No corrosion
304 SS Rivets	No corrosion, thin white corrosion products at rivet countersinks in panel
Faying surfaces	Thin white corrosion products, panel surface etched
#2	No corrosion
304 SS Rivets	No corrosion, thin white corrosion products at rivet countersinks in panel
Faying surfaces	Thin white corrosion products, panel surface etched
#3	No corrosion
304 SS Rivets	No corrosion, thin white corrosion products at rivet countersinks in panel
Faying surfaces	Thin white corrosion products, panel surface etched
#4	No corrosion
Ni-Cu 400 Rivets	No corrosion, thin white corrosion products at rivet countersinks in panel
Faying surfaces	Thin white corrosion products, panel surface etched
#5	No corrosion
Ni-Cu 400 Rivets	No corrosion, thin white corrosion products at rivet countersinks in panel
Faying surfaces	Thin white corrosion products, panel surface etched
#6	No corrosion
Ni-Cu 400 Rivets	No corrosion, thin white corrosion products at rivet countersinks in panel
Faying surfaces	Thin white corrosion products, panel surface etched

Table 1. Specimens After Three Months of Exposure in Tidewater (Cont'd)

Specimen	Remarks
Panel G9B	6061-T6 anodized[3] and painted,[2] no electrical contact between panel fasteners or strips
Front[1]	Paint failed at 3 small points on top edge, no paint failure on surface, barnacles on sealant around strips
Back	No paint failure, barnacles on sealant around washers and nuts
Strips	13V-11Cr-3Al, 18-8 SS screws, silver plated A-286 nuts, delrin sleeves, strips and washers
#1	No corrosion
Sealant-DC780	No failure, good adhesion to delrin strip and to panel
Delrin insulation	No failure
Fasteners	No corrosion
Faying surfaces	No paint failure
#2	No corrosion
Sealant-DC780	Failed on one bolt head, otherwise intact
Delrin insulation	No failure
Fasteners	Slight rust stains on head of one bolt where sealant failed
Faying surfaces	No paint failure

1. Surface with strips
2. Paint system:
   Wash primer - phosphoneal, 1 coat
   Primer - 1 coat epoxy and 1 coat polyurethane
   Top coat - 2 coats, color coded polyurethane
3. Chronic acid anodized

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13. ABSTRACT

A sea water exposure program was initiated to determine (1) the effects of galvanic and crevice corrosion on selected combinations of alloys; and (2) the efficacy of sealing compounds, paint coatings and galvanic anodes for preventing corrosion, crevice corrosion and galvanic corrosion. Evaluations of the results of 91 days of exposure at mean tide level in sea water showed that:

1. A polyurethane paint system
   (a) effectively protected
      (1) anodized 6061-T6 aluminum alloy
      (2) glass reinforced plastic
      (3) 6Al-4V titanium alloy
      (4) 13V-11Cr-3Al titanium alloy
   (b) prevented galvanic corrosion between dissimilar metal combinations
   (c) prevented crevice corrosion
2. The sealing compounds for excluding sea water from crevices in order of effectiveness from best to worse were:
   (a) PR1532
   (b) DC780
   (c) DC93046
   (d) PR1422
   (e) PR1527
   (f) DC11
   (g) sprayed PVC.

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ABSTRACT (cont'd)

3. No corrosion occurred on:
   (a) Unprotected anodized 6061-T6 aluminum alloy fasteners,
   (b) 5052 aluminum alloy rivets,
   (c) A-286 corrosion resistant steel fasteners,
   (d) 6Al-4V titanium alloy fasteners.
4. Cadmium plated steel washers
   (a) corroded galvanically when in contact with titanium and A-286 corrosion resistant steel fasteners
   (b) by ordinary corrosion when isolated from 6061-T6 aluminum alloy fasteners by an anodic coating.
5. Delrin plastic strips, sleeves and washers were effective in isolating metal parts from each other; hence, preventing galvanic corrosion.
6. A zinc anode prevented corrosion and galvanic corrosion on an anodized aluminum alloy 6061-T6 panel with anodized 6061-T6 strips attached to it with Type 304 stainless steel and nickel-copper 400 alloy rivets.
7. A zinc anode did not prevent corrosion at the faying surfaces between a 6061-T6 aluminum alloy panel and 13V-11Cr-3Al titanium alloy strips but it did prevent corrosion and galvanic corrosion on the exposed surfaces.